NASA TECHNICAL MEMORANDUM

NASA TM X- 73957-6

NASA TM X- 73957-6

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LaRC DESIGN ANALYSIS REPORT

FOR

NATIONAL TRANSONIC FACILITY

FOR

304 STAINLESS STEEL TUNNEL SHELL

FATIGUE ANALYSIS

VOL. 6S

BY

JAMES W. RAMSEY, JR., JOHN T. TAYLOR, JOHN F. WILSON,
CARL E. GRAY, JR., ANNE D. LEATHERMAN, JAMES R. ROOKER,
AND JOHNNY W. ALLRED

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Langley Research Center
Hampton, Virginia 23665

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16. Abstract

This report contains the results of extensive computer (finite element, finite difference and numerical integration), thermal, fatigue, and special analyses of critical portions of a large pressurized, cryogenic wind tunnel (National Transonic Facility). The computer models, loading and boundary conditions are described. Graphic capability was used to display model geometry, section properties, and stress results. A stress criteria is presented for evaluation of the results of the analyses. Thermal analyses were performed for major critical and typical areas. Fatigue analyses of the entire tunnel circuit is presented.

The major computer codes utilized are: SPAR - developed by Engineering Information Systems, Inc. under NASA Contracts NAS8-30536 and NAS1-13977; SALORS - developed by Langley Research Center and described in NASA TN D-7179; and SRA - developed by Structures Research Associates under NASA Contract NAS1-10091; "A General Transient Heat-Transfer Computer Program for Thermally Thick Walls" developed by Langley Research Center and described in NASA TM X-2058.

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NATIONAL TRANSONIC FACILITY

TUNNEL SHELL

NASA - LaRC

FATIGUE ANALYSIS

304 STAINLESS STEEL

SEPTEMBER 1976

VOLUME 6S

LaRC CALCULATIONS

FOR THE

NATIONAL TRANSONIC FACILITY

TUNNEL SHELL

DATE: SEPTEMBER, 1976

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This report is one volume of a Design Analysis Report prepared by LaRC on portions of the pressure shell for the National Transonic Facility. This report is to be used in conjunction with reports prepared under NASA Contract NAS1-13535(c) by the Ralph M. Parsons Company (Job Number 5409-3 dated September 1976) and Fluidyne Engineering Corporation (Job Number 1060 dated September 1976). The volumes prepared by LaRC are listed below:

1. Finite Difference Analysis of Cone/Cylinder Junction (304 S.S.) Vol. 1, NASA TM X-73957-1.

2. Finite Element Analysis of Corners #3 and #4 (304 S.S.), Vol. 2S, NASA TM X-73957-2.

3. Finite Element Analysis of Plenum Region Including Side Access Reinforcement, Side Access Door and Angle of Attack Penetration (304 S.S.), Vol. 3S, NASA TM X73957-3.

4. Thermal Analysis (304 S.S.) Vol. 4S, NASA TM X73957-4.

5. Finite Element and Numerical Integration Analyses of the Bulkhead Region (304 S.S.), Vol. 5S, NASA TM X73957-5.

6. Fatigue Analysis (304 S.S.), Vol. 6S, NASA TM X73957-6.

7. Special Studies (304 S.S.), Vol. 7S, NASA TM X73957-7.

NTF DESIGN CRITERIA
FOR 304 STAINLESS STEEL

GENERAL

THE DESIGN OF THE PRESSURE SHELL REFLECTED IN THIS REPORT SATISFIES THE DESIGN REQUIREMENTS OF THE ASME BOILER AND PRESSURE VESSEL CODE, SECTION VIII, DIVISION 1. SINCE DIVISION 1 DOES NOT CONTAIN RULES TO COVER ALL DETAILS OF DESIGN, ADDITIONAL ANALYSES WERE PERFORMED IN AREAS HAVING COMPLEX CONFIGURATIONS SUCH AS THE CONE CYLINDER JUNCTIONS, THE GATE VALVE BULKHEADS, THE BULKHEAD-SHELL ATTACHMENTS, THE PLENUM ACCESS DOORS AND REINFORCEMENT AREAS, THE ELLIPTICAL CORNER SECTIONS, AND THE FIXED REGION (RING S8) OF THE TUNNEL. THE DIVISION 1 DESIGN CALCULATIONS, THE ADDITIONAL ANALYSES AND THE CRITERIA FOR EVALUATION OF THE RESULTS OF THE ADDITIONAL ANALYSES TO ENSURE COMPLIANCE WITH THE INTENT OF DIVISION 1 REQUIREMENTS ARE CONTAINED IN THE TEXT OF THIS REPORT. THE DESIGN ANALYSES AND ASSOCIATED CRITERIA CONSIDERED BOTH THE OPERATING AND HYDROSTATIC TEST CONDITIONS.

IN CONJUNCTION WITH THE DESIGN, A DETAILED FATIGUE ANALYSIS OF THE PRESSURE SHELL WAS ALSO PERFORMED UTILIZING THE METHODS OF THE ASME CODE, SECTION VIII, DIVISION 2.

MATERIAL

THE PRESSURE SHELL MATERIAL SHALL BE ASME, SA-240, GRADE 304 FOR PLATE AND SA-182, GRADE F304 FOR FORGINGS. THE MATERIAL PROPERTIES AT TEMPERATURES EQUAL TO OR BELOW 150°F ARE AS FOLLOWS:

(A) PLATE

YIELD = 30.0 KSI
ULTIMATE = 75.0 KSI

(B) WELDS (AUTOMATIC, SEMIAUTOMATIC, OR "STICK")

YIELD = 30.0 KSI
ULTIMATE = 75.0 KSI

OPERATING, DESIGN AND TEST CONDITIONS

THE OPERATING, DESIGN AND TEST CONDITIONS FOR THE TUNNEL PRESSURE SHELL AND ASSOCIATED SYSTEMS AND ELEMENTS ARE SUMMARIZED BELOW:

1. **OPERATING MEDIUM**

ANY MIXTURE OF AIR AND NITROGEN

2. **DESIGN TEMPERATURE RANGE**

MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT, EXCEPT IN THE REGION OF THE PLENUM BULKHEADS AND GATE VALVES INSIDE A 23-FOOT, 4-INCH DIAMETER, FOR WHICH THE TEMPERATURE RANGE IS MINUS 320 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT.

3. **PRESSURE RANGE**

	TUNNEL CONFIGURATION	OPERATING PRESSURE RANGE, PSIA	DESIGN PRESSURES PSID
A.	CONDITION I - PLENUM ISOLATION GATES OPEN AND TUNNEL OPERATING:		
	TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
	PLENUM (PLENUM PRESSURE IS LIMITED TO .4 TO 1 TIMES THE REMAINDER OF THE TUNNEL CIRCUIT	3.3 to 130	A. 15 EXTERNAL B. 119 INTERNAL
	BULKHEAD		56 (EXTERNAL TO PLENUM)
B.	CONDITION II - PLENUM ISOLATION GATES OPEN AND TUNNEL SHUTDOWN:		
	ENTIRE TUNNEL CIRCUIT	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
	BULKHEAD		0
C.	CONDITION III - PLENUM ISOLATION GATES AND ACCESS DOORS CLOSED:		
	TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL

PLENUM (PLENUM OPERATING PRESSURE CAN EXCEED THE PRESSURE IN THE REMAINDER OF THE TUNNEL CIRCUIT BY 24 PSI, BUT DOES NOT EXCEED THE 130 PSIA MAXIMUM OPERATING PRESSURE)	0 to 130	A. 15 EXTERNAL B. 119 INTERNAL
BULKHEAD		A. 25 (INTERNAL TO PLENUM) B. 119 (EXTERNAL TO PLENUM) FOR MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT *C. 115.7 (EXTERNAL TO PLENUM) FOR PLUS 151 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT

*OPERATING PROCEDURES LIMIT PRESSURES TO THAT SHOWN.

D. CONDITION IV - PLENUM ISOLATION GATES CLOSED AND ACCESS DOORS OPEN:

TUNNEL CIRCUIT EXCEPT PLENUM	8.3 to 130	A. 8 EXTERNAL B. 119 INTERNAL
PLENUM	14.7	0
BULKHEAD		A. 119 (EXTERNAL TO PLENUM) FOR MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT *B. 115.7 (EXTERNAL TO PLENUM) FOR PLUS 151 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT

*OPERATING PROCEDURES LIMIT PRESSURES TO THAT SHOWN.

4. HYDROSTATIC TEST DESIGN CONDITIONS

THE PRESSURE SHELL WAS DESIGNED FOR HYDROSTATIC TEST IN ACCORDANCE WITH THE REQUIREMENTS OF THE ASME CODE, SECTION VIII, DIVISION 1. THE TEST PRESSURES SHALL BE AS FOLLOWS. PRESSURE SHELL TEMPERATURE SHALL BE EQUAL TO OR BELOW 100°F DURING HYDROSTATIC TESTS.

CONDITION (1) - MAXIMUM INTERNAL PRESSURE CONDITION FOR THE ENTIRE TUNNEL CIRCUIT

$$PH_1 = 1.5\ (119)\ \left(\frac{18.7}{18.2}\right) + \text{HYDROSTATIC HEAD}$$

$$= 183.4 \text{ PSI} + \text{HYDROSTATIC HEAD}$$

CONDITION (2) - MAXIMUM DIFFERENTIAL PRESSURE CONDITION ACROSS THE PLENUM BULKHEADS

$$PH_2 = 1.5\ \left(\frac{18.7}{18.2}\right)\ (119) + \text{HYDROSTATIC HEAD}$$

$$= 183.4 + \text{HYDROSTATIC HEAD}$$

$$PH_2^* = 1.5\ (115.7)\ \left(\frac{18.7}{17.7}\right) + \text{HYDROSTATIC HEAD}$$

$$= 183.4 + \text{HYDROSTATIC HEAD}$$

*TUNNEL OPERATION LIMITATIONS PRECLUDE PRESSURE DIFFERENTIALS ACROSS BULKHEADS IN EXCESS OF 115.7 PSI FOR BULKHEAD AND GATE TEMPERATURES IN EXCESS OF 150°F.

CONDITION (3) - MAXIMUM REVERSE DIFFERENTIAL PRESSURE CONDITION ACROSS THE PLENUM BULKHEADS

$$PH_3 = 1.5\ \left(\frac{18.7}{18.2}\right)\ (25) = 38.5 \text{ PSI}$$

THE PRESSURE SHELL EXCEPT FOR THE PLENUM SHALL BE PRESSURIZED TO 144.9 PSIG. THE PLENUM SHALL BE PRESSURIZED TO 183.4 PSIG.

PRESSURE SHELL STRESS EVALUATION CRITERIA

THIS CRITERIA ESTABLISHES THE BASIS FOR ANALYSIS AND DESIGN OF THE PRESSURE SHELL SO IT WILL MEET OR EXCEED ALL OF THE REQUIREMENTS OF SECTION VIII, DIVISION 1 OF THE ASME BOILER AND PRESSURE VESSEL CODE AND CAN BE STAMPED WITH A DIVISION 1 "U" STAMP.

1. SECTION VIII, DIVISION 1, DIRECT APPLICATION

(A) THE MAXIMUM ALLOWABLE STRESS (S)

$S = 18.2$ KSI (-320°F TO +150°F)

$S = 17.7$ KSI (-320°F TO +200°F)

(B) PRIMARY BENDING PLUS PRIMARY MEMBRANE STRESSES

THE LOCAL MEMBRANE STRESSES ARE NOT GENERALLY CONSIDERED IN SECTION VIII, DIVISION 1 DESIGNS. HOWEVER, FOR THE PURPOSE OF DESIGNING LOCAL REINFORCEMENT AT BRACKETS, RINGS OR PENETRATIONS NOT COVERED BY DESIGN BASED ON STRESS ANALYSIS, THE LOCAL SHELL MEMBRANE STRESS SHALL BE:

$$P_b + P_m \leq 1.5\ SE$$

NOTE: E IS JOINT EFFICIENCY

2. IN REGIONS OF THE PRESSURE SHELL WHERE DIVISION 1 DOES NOT CONTAIN RULES TO COVER ALL DETAILS OF DESIGN (REF. U-2(g)), ADDITIONAL ANALYSES WERE PERFORMED UTILIZING THE GUIDELINES OF THE ASME CODE, SECTION VIII, DIVISION 2, APPENDIX 4, "DESIGN BASED ON STRESS ANALYSIS." THE BASIC STRESS CRITERIA FOR DIVISION 2 IS REPRESENTED IN FIGURE 4-130.1 AND RESTATED BELOW INDICATING ANY MODIFICATIONS OR EXCESS REQUIREMENTS APPLIED TO IT TO REMAIN WITHIN THE INTENT OF DIVISION 1 AND TO OBTAIN A DIVISION 1 STAMP.

A. GENERAL PRINCIPAL MEMBRANE STRESS

MAXIMUM ALLOWABLE STRESS

$S = 18.2$ KSI (-320°F TO +150°F)

$S = 17.7$ KSI (-320°F TO +200°F)

MAXIMUM ALLOWABLE STRESS INTENSITY

$S_m = 20.0$ KSI (-320°F TO +300°F)

B. PRIMARY GENERAL MEMBRANE STRESS INTENSITY

$$P_m \leq S_m$$

AND IN ORDER TO COMPLY WITH DIVISION 1, THE MAXIMUM PRINCIPAL MEMBRANE STRESS MUST BE:

$$P_m^* \leq S$$

NOTE: THE * IS USED TO DENOTE THAT MAXIMUM PRINCIPAL STRESSES ARE TO BE COMPUTED FOR THE GIVEN LOADING CONDITION. THE INTENT IS TO DETERMINE THE STRESSES WHICH REPRESENT THE HOOP STRESSES AND MERIDIONAL STRESSES WHICH ARE THE STRESSES USED IN DIVISION 1 COMPUTATIONS.

C. DESIGN LOADS, PRIMARY LOCAL MEMBRANE STRESS INTENSITY

$$P_L \leq 1.5\ S_m$$

NOTE: LOCAL MEMBRANE STRESS INTENSITY IS DEFINED IN ACCORDANCE WITH DIVISION 2, APPENDIX 4-112(i). THE TOTAL MERIDIONAL LENGTH IS CONSIDERED TO BE 1.0 $\sqrt{RT}$.

D. DESIGN LOADS, PRIMARY LOCAL MEMBRANE PLUS PRIMARY BENDING STRESS INTENSITY

$$P_L + P_b \leq 1.5\ S_m$$

E. OPERATING LOADS, PRIMARY PLUS SECONDARY STRESS INTENSITY

$$P_L + P_b + Q \leq 3\ S_m$$

3. A FATIGUE ANALYSIS WAS CONDUCTED IN ACCORDANCE WITH SECTION VIII, DIVISION 2 WITHOUT MODIFICATION.

4. HYDROSTATIC TEST CONDITION DESIGN CONSIDERATIONS

A. PRESSURE SHELL

IN ACCORDANCE WITH DIVISION 1 OF THE ASME CODE, DESIGN ANALYSIS OF THE PRESSURE SHELL FOR THE HYDROSTATIC TEST CONDITION IS NOT REQUIRED. HOWEVER, IN ORDER TO PROVIDE A SATISFACTORY ENGINEERING DESIGN FOR THE PRESSURE SHELL SPECIAL EMPHASIS WAS GIVEN, AS PROMPTED BY NOTE (1) OF SECTION VIII, DIVISION 1 OF THE ASME CODE, TO FLANGES OF GASKETED JOINTS OR OTHER APPLICATIONS WHERE SLIGHT AMOUNTS OF DISTORTION CAN CAUSE LEAKAGE OR MALFUNCTION. EXAMPLES OF THESE AREAS ARE THE PLENUM, PLENUM ACCESS DOORS, PLENUM ACCESS DOOR REINFORCEMENT, THE BULKHEADS, AND BULKHEAD FLANGES.

B. SUPPORT RINGS

DESIGN OF THE PRESSURE SHELL SUPPORT RINGS, INCLUDING

THE CORNER RINGS, FOR THE HYDROSTATIC TEST CONDITION, COMPLIES WITH THE FOLLOWING·

(A) THE COMBINED VALUE OF THE SHELL CIRCUMFERENTIAL PRESSURE STRESS, S_1 AND SHELL

BENDING STRESS S_2, RESULTING FROM ACTION OF A

PORTION OF THE SHELL AS AN INNER FLANGE OF THE RING, SHALL NOT EXCEED 0.8 WELD YIELD STRESS:

$S_1 + S_2 \leq 0.8$ WELD YIELD STRESS,

WHERE, FOR SUPPORT RINGS NOT ANALYZED BY FINITE ELEMENT TECHNIQUES,

$S_1 = P_H \left(\frac{R}{T}\right) + .6\ P_H$; P_H INCLUDES HYDROSTATIC HEAD CORRECTION, AND

S_2 = RING BENDING STRESS AT INNER FLANGE, BASED ON AN EFFECTIVE WIDTH OF THE PRESSURE SHELL ACTING AS AN INNER FLANGE OF THE RING OF 1.1 MULTIPLIED BY THE SQUARE ROOT OF $D_O\ T$.

(B) THE BENDING STRESS, S_{2F} ON THE OUTSIDE FLANGE

SHALL NOT EXCEED .9 WELD YIELD STRESS. (IN THE COMPUTER ANALYSIS ALL LOADING CONDITIONS ARE LIMITED TO .9 S_Y ON THE OUTER FLANGE.)

(C) BRACKETS AND SUPPORT PAD WELDMENTS

THE DESIGN FOR ALL LOADING CONDITIONS INCLUDING THE HYDROSTATIC TEST CONDITION OF THOSE PORTIONS OF BRACKETS AND SUPPORT PAD WELDMENTS WHICH ARE ATTACHED TO THE PRESSURE SHELL BUT NOT ON THE SURFACE OF THE SHELL SHALL COMPLY WITH THE REQUIREMENTS OF THE AISC CODE, I.E. MAXIMUM STRESS IN TENSION EQUALS .6 S_Y, ETC.

NTF 304 S. S. SHELL
FATIGUE ANALYSIS

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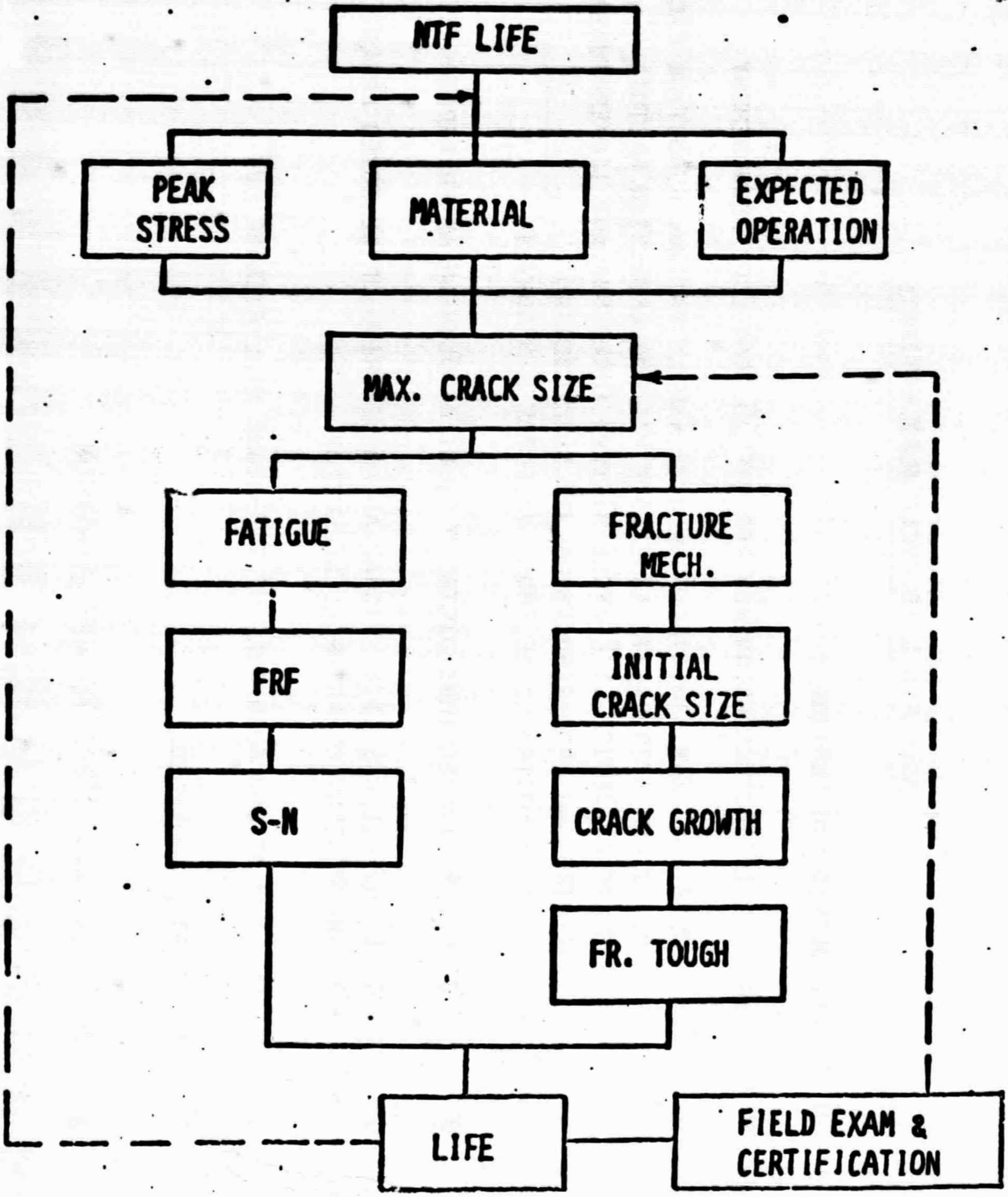
APPROACH



NASA LANGLEY RESEARCH CENTER

Taylor, J.T.; Lewis, P.E.; and Ramsey, J.W.,Jr.: A Procedure for Verifying the Structural Integrity of an Existing Pressurized Wind Tunnel. ASME National Pressure Vessel Conference, June 1974; and ASME JEMT, October 1974.

BASIS FOR LIFE CYCLE FAT. ESTIMATE

→ SHEAR WAVE ULTRASONIC TESTING

- BASIS FOR INSPECTION FREQUENCY FOR NTF 50 YEAR LIFE REQUIREMENT

  1. ASSUME .03" MAX. INITIAL FLAW SIZE (APPLY FATIGUE REDUCTION FACTOR)
  2. APPLY OTHER APPROPRIATE ASME CODE FATIGUE REDUCTION FACTORS
  3. USE NTF PROJECTED LIFE CYCLE HISTORY (PRESSURE AND TEMPERATURES)
  4. USE STRESSES FROM RESULTS OF NTF SHELL DESIGN
  5. DETERMINE FATIGUE LIFE FROM ASME CODE S-N CURVES

- NO SECONDARY INSPECTIONS DICTATED BY UT RESULTS OR AFTER REPAIR

- ROUTINE INSPECTIONS (I.E. VISUAL AND MONITORING OF SELECTED AREAS) ASSUMED TO BE INDEPENDENT OF MATERIAL SELECTION

- ASSUME VARIATIONS FROM FULL UT TECHNIQUE WILL AVERAGE OUT

- NO REPAIRS INCLUDED

- NO CRACKS → INFINITE LIFE EVERYWHERE

REFERENCES

1. ASME Boiler and Pressure Vessel Code. 1974 Edition.

2. Taylor, J.T.; Lewis, P.E.; and Ramsey, J.W.,Jr.: A Procedure for Verifying the Structural Integrity of an Existing Pressurized Wind Tunnel. ASME National Pressure Vessel Conference, June 1974; and ASME JEMT, October 1974.

3. McCormick, Caleb W.: The NASTRAN User's Manual. NASA SP-222(01), June 1972.

4. Cohen, G. A.: User Document for Computer Programs for Ring-Stiffened Shell of Revolution. NASA CR-2086, March 1973.

5. ASME Boiler and Pressure Vessel Code. Section VIII, Division 2, 1974 Edition.

6. O'Donnel, W. J.; and Purdy, C.M.: The Fatigue Strength of Members Containing Cracks. Journal of Engineering for Industry, May 1964.

7. Ramsey, J.W.,Jr.: Stress Concentration Factors for Circular, Reinforced Penetrations in Pressurized Cylindrical Shells. Ph.D. Dissertation, University of Virginia, May 1975.

8. NTF Operational Profile by Dr. W. S. Lassiter, dated 12/22/75

9. NTF Operational Procedures for Minimizing Moisture Condensation by Dr. W. S. Lassiter, dated 1/16/76

10. Vibration Committee Memo by Dr. J. W. Ramsey, Jr., updated 1/18/76

NO

ASME CODE SECTION VIII

DIVISION 1 PROVIDES REQUIREMENTS FOR:

- DESIGN
- FABRICATION
- INSPECTION
- CERTIFICATION
- HYDRO 1.5 X DESIGN PRESSURE (36 KSI)
- PNEUMATIC 1.25 X DESIGN PRESSURE (30 KSI)

DIVISION 2 PROVIDES FOR IMPROVED QUALITY BY:

- MORE RESTRICTION ON CHOICE OF MATERIALS
- MORE PRECISE DESIGN PROCEDURES
- PROHIBITS SOME COMMON DESIGN DETAILS
- FABRICATION PROCEDURES ARE SPECIFICALLY DELINEATED
- MORE COMPLETE TESTING AND INSPECTION
- HYDRO 1.25 X DESIGN PRESSURE (40 KSI)
- PNEUMATIC 1.15 X DESIGN PRESSURE (36KSI)
- PROVIDES FOR FATIGUE LIFE DUE TO CYCLIC PRESSURE/TEMPERATURES

NTF NOW APPROACHES THIS WITH DIV. I ALLOWABLES

DESIGN (STRESS) CRITERIA

I. SECTION VIII - DIVISION I

PRESSURE: -15 TO 119 PSIG
TEMPERATURE: -320 TO 150°F

II. MATERIALS

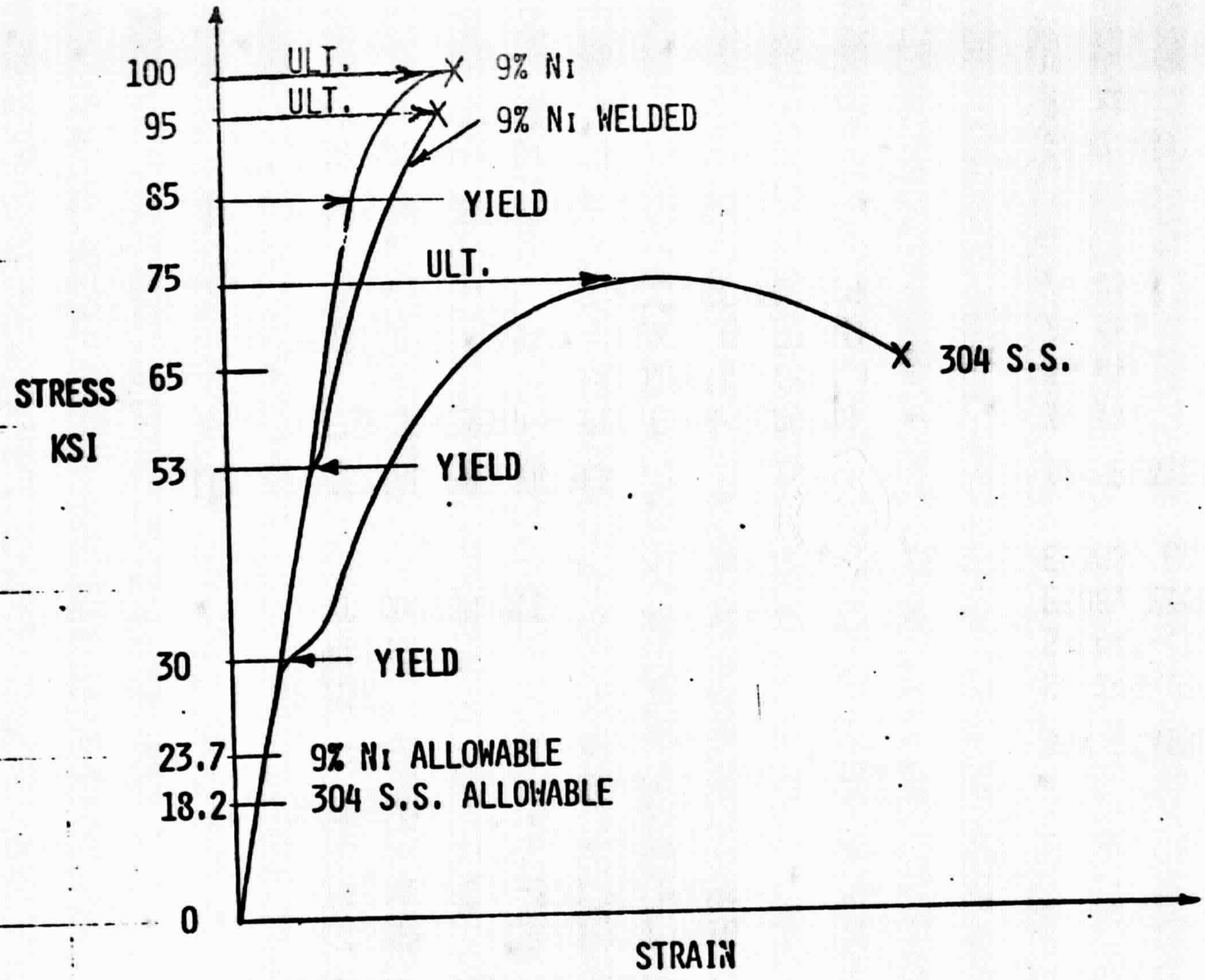
	304 STAINLESS STEEL
PLATE	SA-240-(304)
FORGINGS	SA-473-(304)
WELD CONSUMABLES	E308, E308L ER308, ER308L

III. MATERIAL PROPERTIES

	(2" PLATE)
YIELD STRENGTH - PLATE OR FORGING	30 KSI
WELD METAL (MIN.)	30 KSI
TENSILE STRENGTH - PLATE OR FORGING	75 KSI
WELD METAL (MIN.)	75 KSI

IV. ALLOWABLE STRESSES (150°F)

SECTION VIII DIV. I	18.2 KSI
SECTION VIII DIV. II	20 KSI



STRESS-STRAIN RELATIONSHIPS
FOR
NTF SHELL MATERIALS

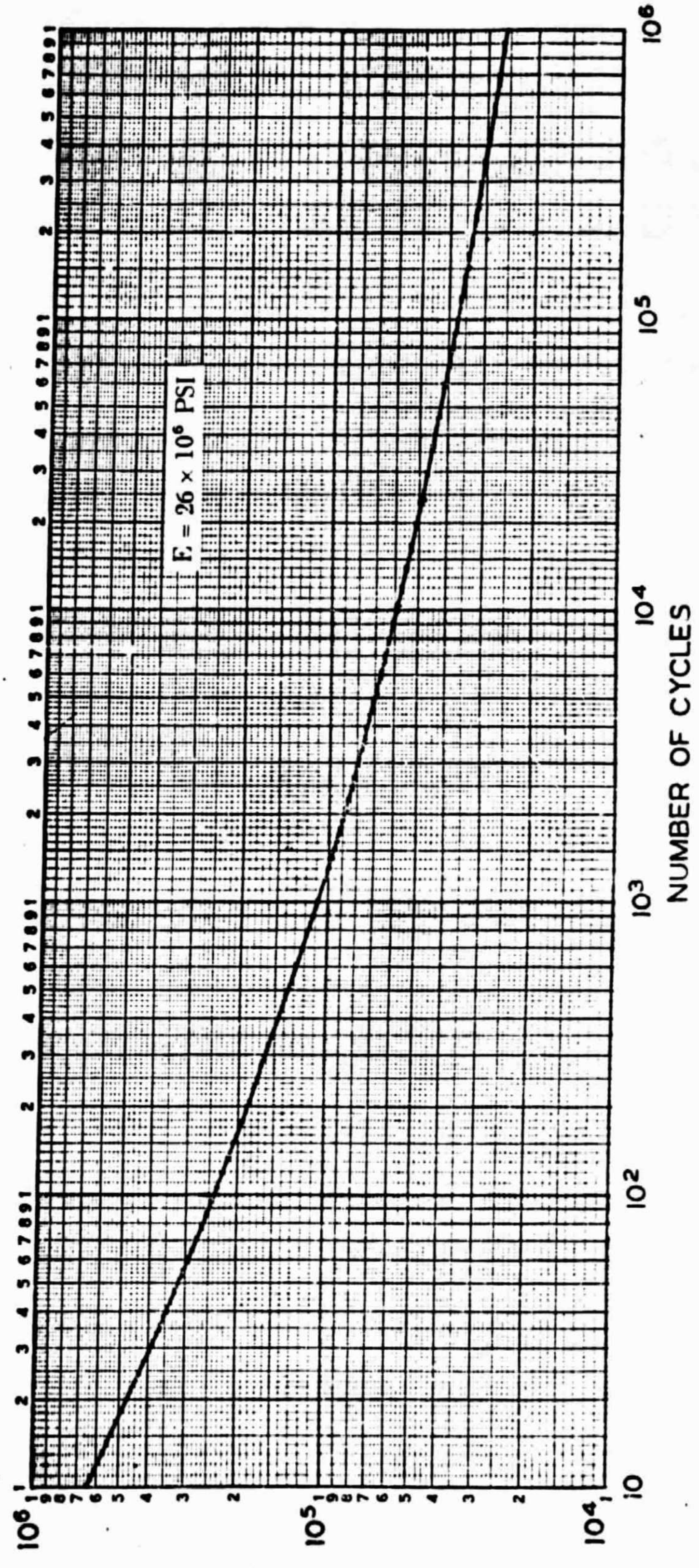


FIG. 5-110.2 DESIGN FATIGUE CURVE FOR SERIES 3XX HIGH-ALLOY STEELS, NICKEL-CHROMIUM IRON ALLOY, NICKEL-IRON-CHROMIUM ALLOY, AND NICKEL-COPPER ALLOY FOR TEMPERATURES NOT EXCEEDING 800 F

NTF CRYOGENIC DUTY CYCLES

CASE	PROGRAM	POLARS PER PROGRAM	MIX FACTOR	PROGRAMS PER YEAR	POLARS PER YEAR
I-A	CRUISE A/C	169	30	15	2400
II	MANEUVERING A/C	208	30	12	2400
III	RN, M, Q EFFECTS	109	40	30	3200
			TOTAL		8000

FIGURE 1

NTF OPERATIONAL PROFILE

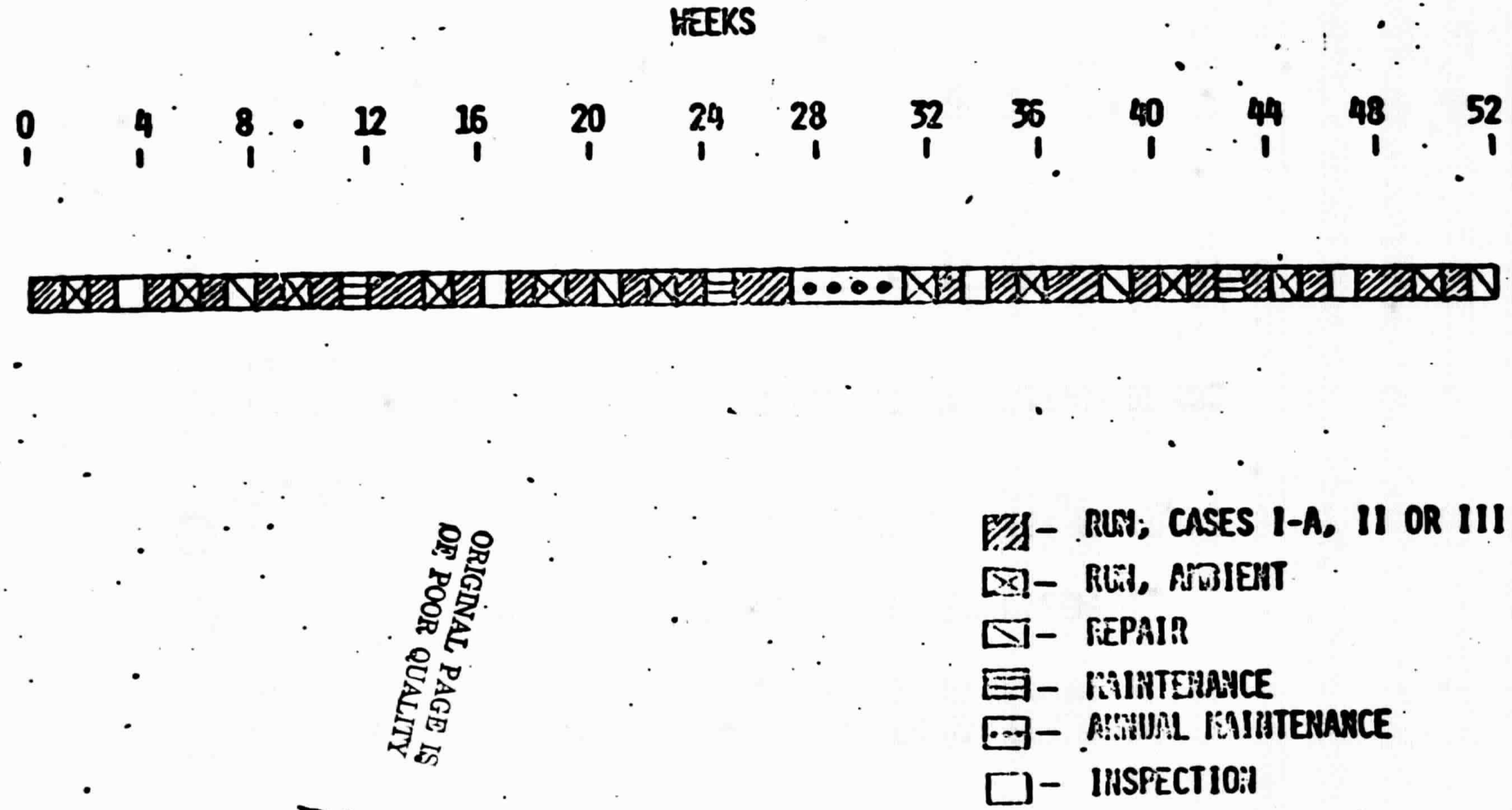


FIGURE 2

ASSUMPTIONS

- ENTIRE TUNNEL BROUGHT TO ATMOSPHERE ON FRIDAY FOR WEEKLY INSPECTION - REMAINS AT ATMOSPHERE (T~70°F) OVER WEEKEND
- THREE SHIFTS DURING WEEK AS REQUIRED - NONE ON WEEKEND
- 12 HOURS BETWEEN PROGRAMS FOR MODEL CHANGE - TEST SECTION OPEN FOR CHANGES.
- PERIODIC REPAIR, MAINTENANCE AND INSPECTION DURATION OF ONE WEEK EACH.
- ONE YEARLY 4-WEEK PERIOD FOR MAINTENANCE, THOROUGH INSPECTION.

FIGURE 3

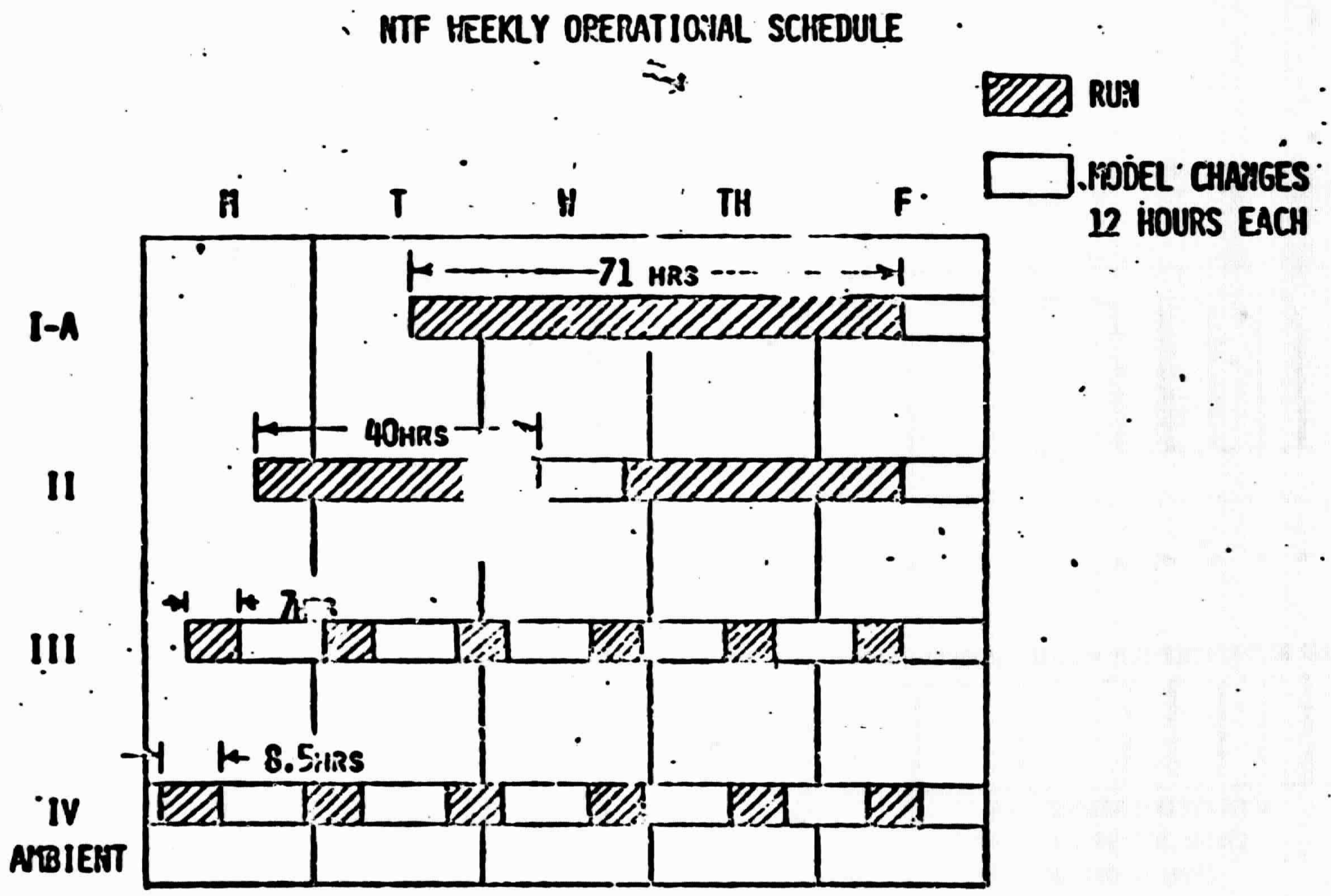

NTF WEEKLY OPERATIONAL SCHEDULE
RUN
MODEL CHANGES
12 HOURS EACH
M
T
W
TH
F
71 HRS
40HRS
8.5HRS
I-A
II
III
IV
AMBIENT

FIGURE 4

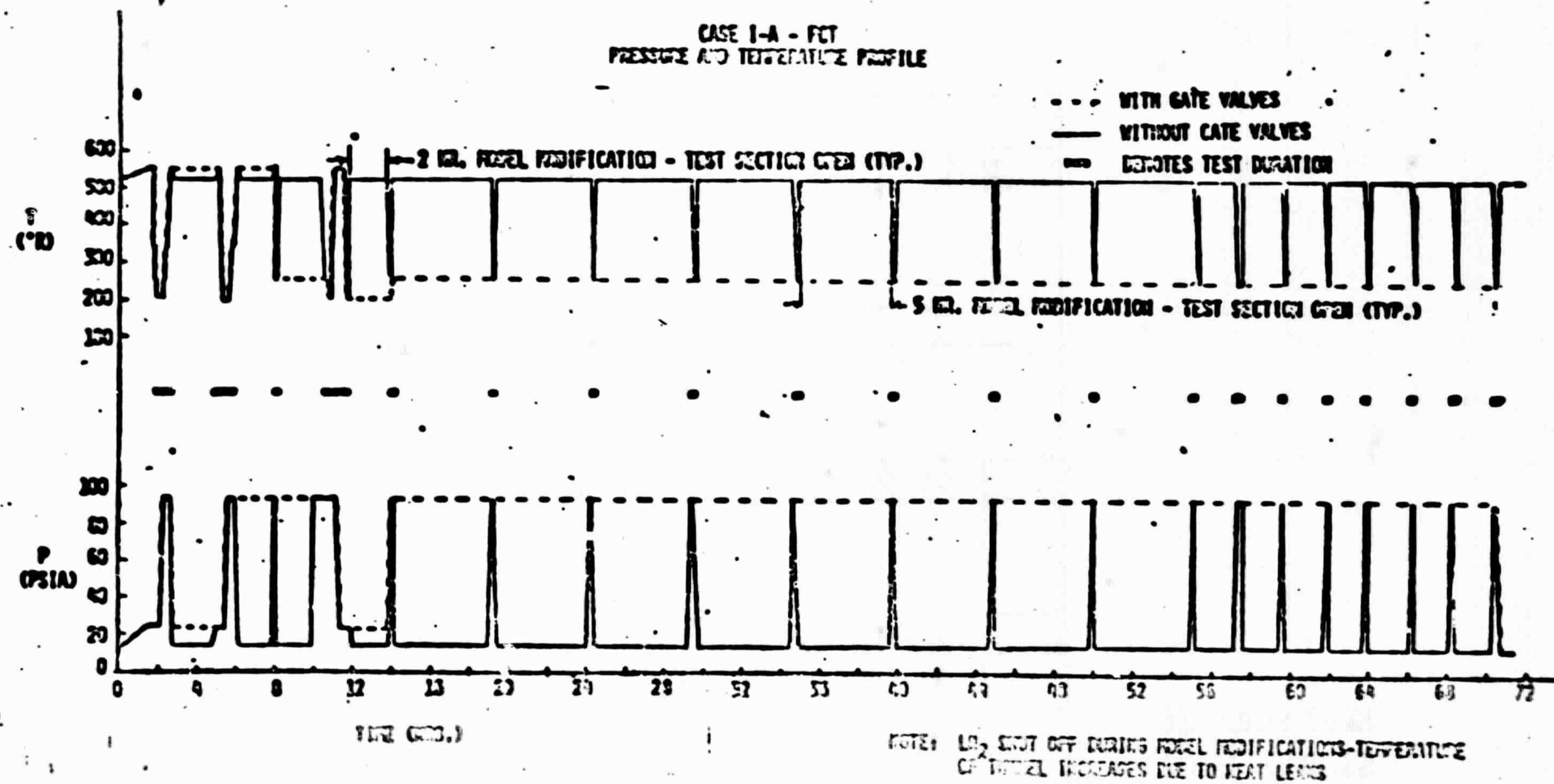

CASE 1-A - FCT
PRESSURE AND TEMPERATURE PROFILE
WITH GATE VALVES
WITHOUT GATE VALVES
DENOTES TEST DURATION
T
(°R)
P
(PSIA)
TIME (HRS.)
NOTE: LO_2 SHUT OFF DURING MODEL MODIFICATIONS-TEMPERATURE

FIGURE 5

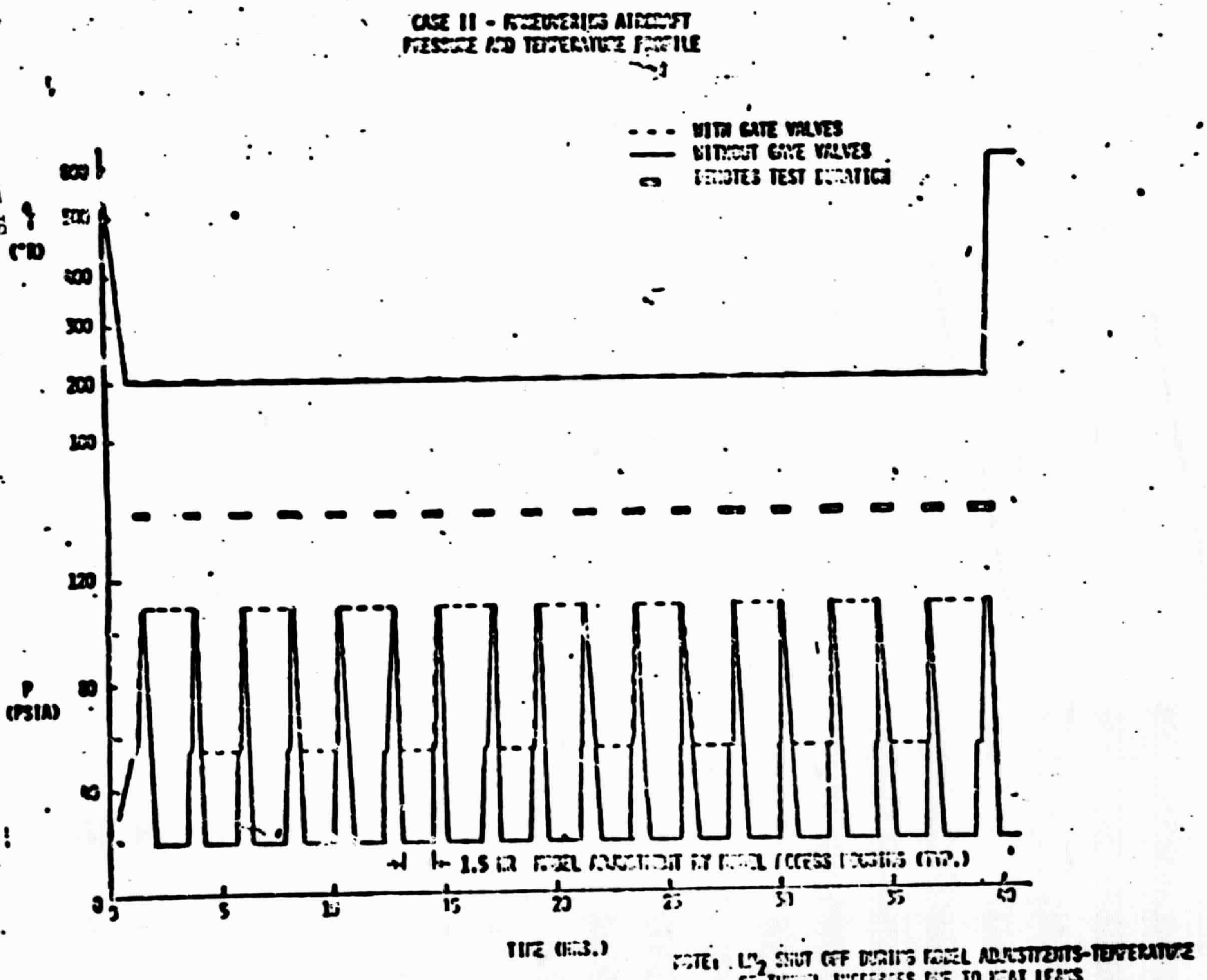

WITH GATE VALVES
WITHOUT GATE VALVES
P
(PSIA)
TIME (HRS.)
0
5
15
20
55
60
200
300
120
80

FIGURE 6

CASE III - BASIC RESEARCH
PRESSURE PROFILE

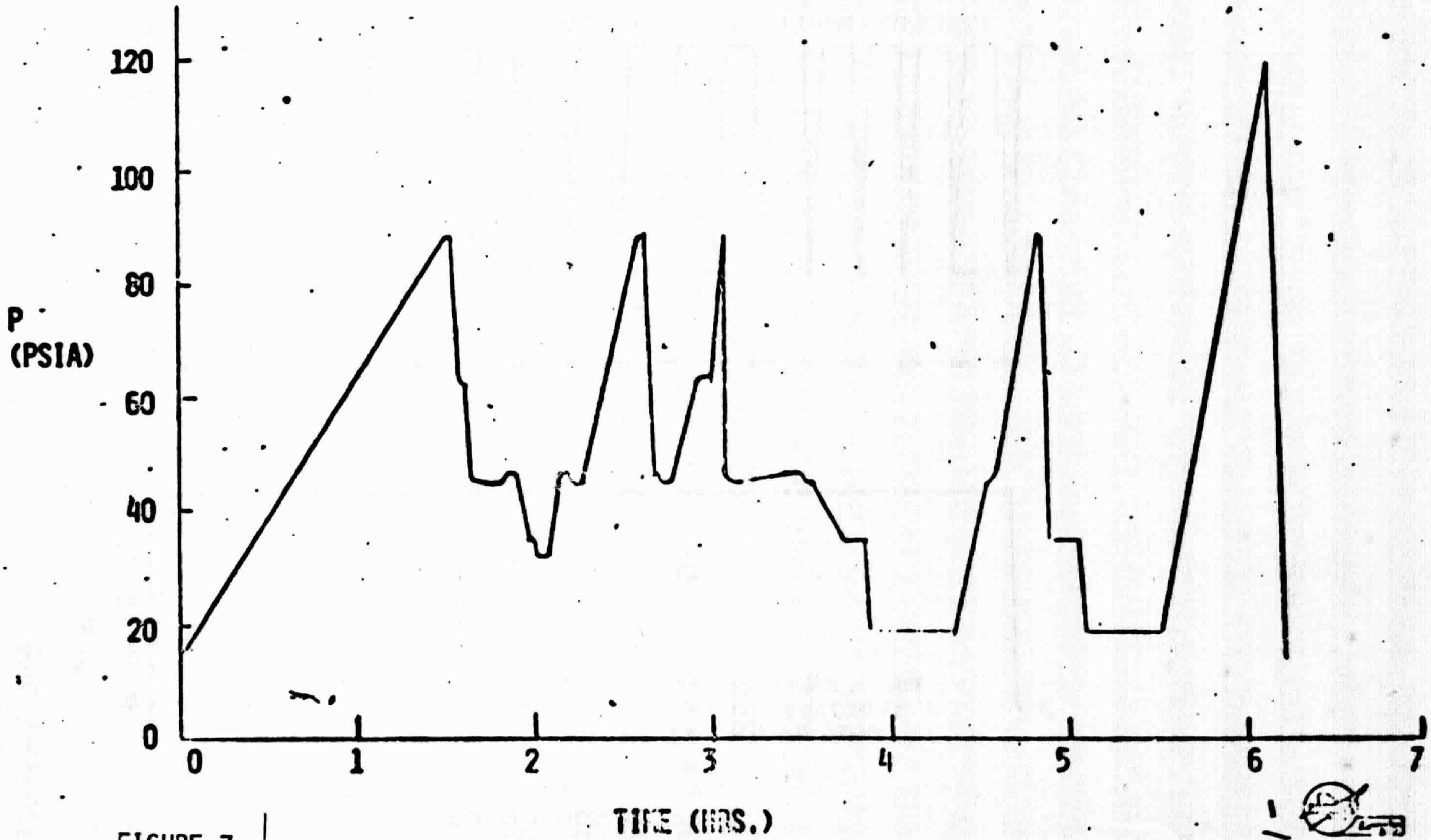


FIGURE 7

CASE III - BASIC RESEARCH TEMPERATURE PROFILE

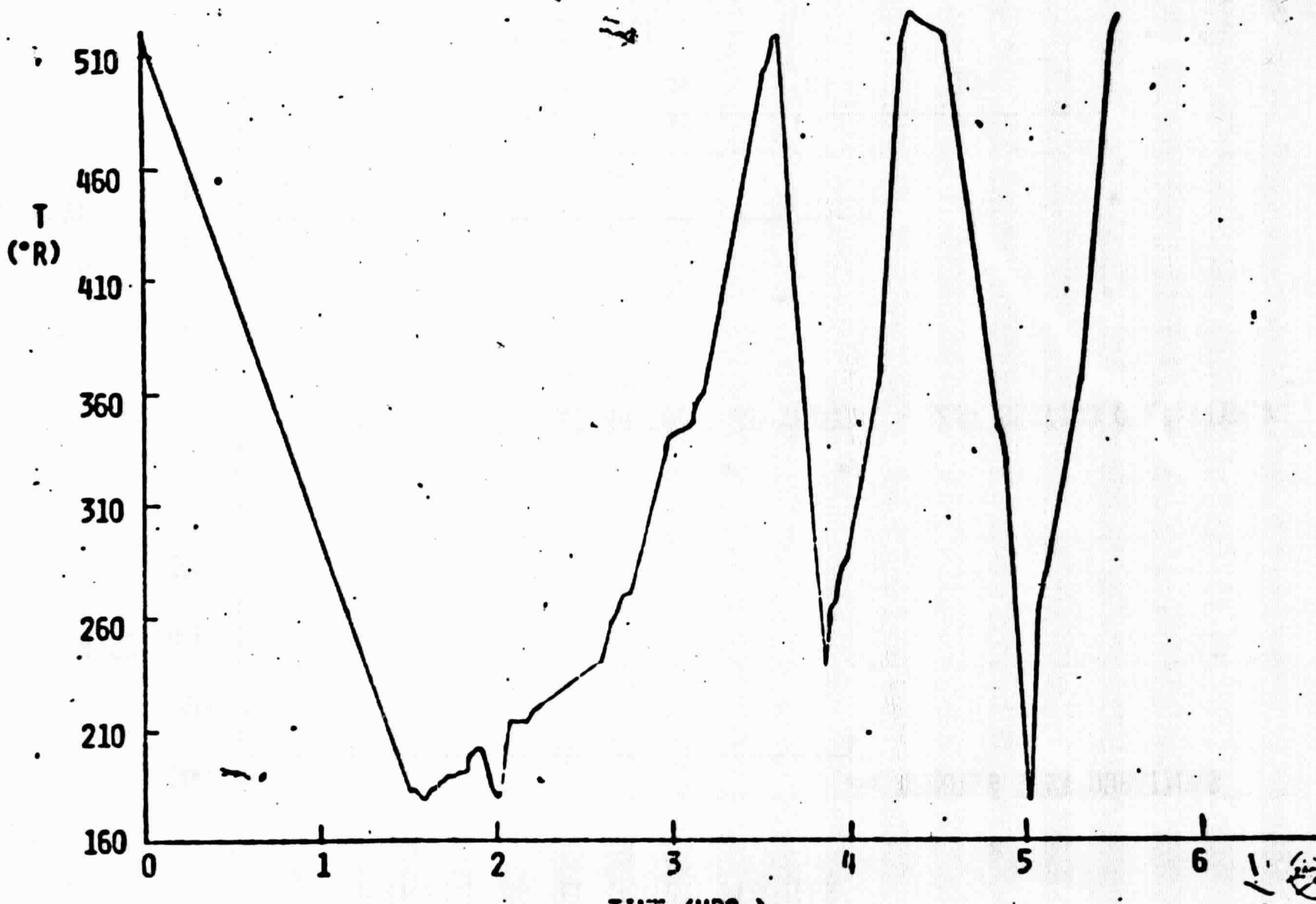


FIGURE 8

CASE IV - AMBIENT MODE

PRESSURE AND TEMPERATURE PROFILES

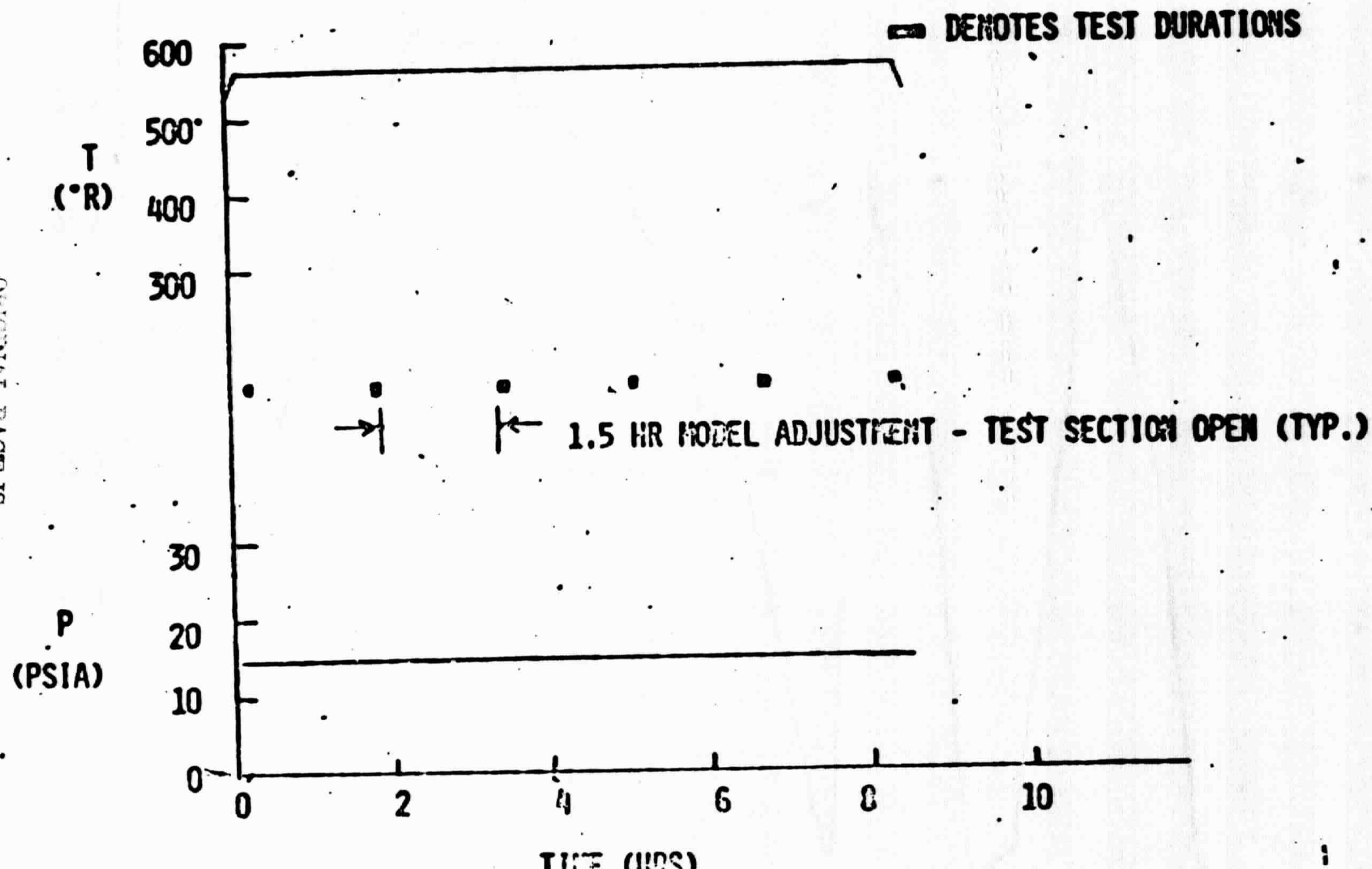


FIGURE 9

OPERATIONAL PROCEDURES

FOR

MINIMIZING MOISTURE IN THE NTF

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4. Cryogenic tests.

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2. Model inspection, repair, and maintenance as required.

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1. Ambient tests.

2. Model change/modification/adjustment during research test programs.

3. Inspection, repair, and maintenance as required.

NOTE: (TBD) indicates that a number is to be determined.

NOTE: Many of these procedures imply manual operations but in reality will be automatic control operations.

DESCRIPTION OF PROCEDURES

CASE A - CONSTRUCTION PHASE

During the construction and installation phases it is highly improbable that the tunnel shell interior and the insulation system can be completely protected from humid environments. It is recommended that once the shell is complete and installation of the insulation commences, all tunnel shell openings to the outside environment be closed and work occur through only those accesses exposed to the environment inside the building (such as the test section) which is conditioned by air conditioning and heating. It is recommended that relative humidity of this conditioned environment not exceed about 50 percent. This will prevent the insulation, upon being installed, from experiencing the very high relative humidities often occurring in the Tidewater area.

CASE B - INITIAL STARTUP AND COOLDOWN

1. Close and secure all tunnel accesses (including exhaust valve).

2. Open vacuum system valve and evacuate tunnel to about 8.3 psia pressure.

3. Close vacuum system valve and backfill tunnel to about one atmosphere with dry heated air.

4. Repeat steps 2 and 3 until tunnel dewpoint is down to about 435°R. During this time maintain tunnel stream temperature above dewpoint temperature.

5. Open vacuum system valve and evacuate tunnel to about 8.3 psia pressure.

6. Close vacuum system valve.

7. Start fan and operate at minimum speed.

8. Open LN_2 valve and inject LN_2 into tunnel at low mass flow rate.

9. When pressure increases to about one atmosphere, open exhaust valve to maintain constant pressure in order to purge system.

10. Never allow stream temperature to exceed 635°R.

11. Purge system by maintaining constant pressure for at least ___(TBD) hours with a stream dewpoint temperature of below 420°R.

12. Maintain stream temperature above dewpoint of stream until dewpoint temperature decreases below 380°R and stream oxygen level less than ___(TBD) percent by volume.

13. Attain test conditions by controlling LN_2 flow rate, fan speed and pressure.

CASE C - CRYOGENIC CONDITION ⟶ AMBIENT CONDITION FOR ENTIRE TUNNEL ACCESS ⟶ CRYOGENIC CONDITION

I. CRYO TO AMBIENT

1. Close LN_2 inlet valve.

2. Operate fan such that stream is heated and maintained at about ___(TBD)^{o}R for at least ____(TBD) hours to warm tunnel interior. Maintain tunnel pressure at about one atmosphere.

3. If at end of a week, shut off fan and allow tunnel to warm up over weekend without opening. Assure that exhaust valve is closed.

4. If not at end of week, continue heating tunnel as in step 2 until liner and insulation considered sufficiently warm for opening tunnel.

5. Shut off fan and close exhaust valve.

6. Open vacuum system valve and evacuate tunnel to 8.3(~~TBD~~) psia with vacuum system.

7. Close vacuum system valve and repressurize tunnel to about one atmosphere with dry, heated air.

8. Repeat steps 6 and 7 until oxygen level in tunnel is at least 20 percent by volume.

9. Open doors to tunnel and perform inspection, repair and maintenance as required. During this time maintain oxygen level at 20 percent or above by volume and air temperature above 500^{o}R by maintaining a positive pressure in the tunnel with dry, heated air.

10. During any time the fan is not turning and the tunnel contains dry, heated air, maintain a positive pressure in the tunnel with the dry air.

II. AMBIENT TO CRYO

1. Close and secure all tunnel accesses.

2. Close dry air inlet valve.

3. Open valve to vacuum system and evacuate tunnel to about 3 psia. Close vacuum system valve.

4. Start fan and operate at minimum speed.

5. Open LN_2 inlet valve and inlet LN_2 at low mass flow rate.

6. Open exhaust valve to maintain pressure at about 15 psia.

7. Maintain stream temperature above dewpoint of stream until dewpoint of stream decreases below $380^{\circ}R$ and oxygen level decreases below ___(TBD) percent by volume.

8. Never allow stream temperature to exceed $635^{\circ}R$.

9. Attain test conditions by controlling LN_2 mass flow rate, fan speed, and pressure.

CASE D - CRYOGENIC CONDITION ⟶ AMBIENT CONDITION FOR TEST SECTION AND PLENUM ACCESS ONLY ⟶ CRYOGENIC CONDITION

I. CRYO TO AMBIENT

1. Close LN_2 inlet valve.
2. Close exhaust valve.
3. Shut off fan.
4. Close and secure gate valves.
5. Relieve plenum and test section of pressure to one atmosphere through plenum pressure control valve.
6. Purge plenum and test section with ___(TBD) lbs per second mass flow of dry, heated air until oxygen content level reaches at least 20 percent by volume and until metal surfaces to be contacted warm sufficiently, depending on work to be performed.
7. Adjust dry air inlet mass flow rate as required in order to maintain a ___(TBD) psia positive pressure, an air temperature of above $500^{\circ}R$, and an oxygen level of at least 20 percent by volume while working in the test section and plenum volume.
8. Perform work as required.

II. AMBIENT TO CRYO

1. Close and secure test section and plenum doors.
2. Close dry air exit and inlet valves.
3. Open gate valve bypass valve and pressurize plenum and test section with cold GN_2 from tunnel.
4. Open gate valves.
5. Start fan and slowly increase speed.
6. Attain test conditions by controlling LN_2 flow rate, fan speed, and pressure.

CASE E - CRYOGENIC CONDITION ——→ MODEL ACCESS VIA MODEL ACCESS HOUSING ——→ CRYOGENIC CONDITION

I. CRYO TO MODEL ACCESS HOUSING INSERTION

1. Close LN_2 inlet valve.

2. Close exhaust valve.

3. Shut off fan.

4. Close and secure gate valves.

5. Relieve plenum and test section pressure to one atmosphere through plenum pressure control valve.

6. Condition model access housing tubes with warm, dry air.

7. Open plenum and test section doors.

8. Insert and seal model access housing tubes.

9. Circulate warm, dry air through housing such that oxygen level is maintained to at least 20 percent by volume and temperature maintained above 500°R.

10. Perform model adjustment/inspection as required.

II. MODEL ADJUSTMENT/INSPECTION TO CRYO

1. Close doors to housing such that dry air environment in housing is maintained once personnel are evacuated.

2. Retract housing tubes.

3. Close and secure test section and plenum doors.

4. Open gate valve bypass valve and pressurize plenum and test section with cold GN_2 from tunnel.

5. Open gate valves.

6. Start fan and slowly increase speed.

7. Attain test conditions by controlling LN_2 flow rate, fan speed, and pressure.

CASE F - AMBIENT CONDITION FOR ENTIRE TUNNEL ACCESS → AMBIENT TEST → AMBIENT CONDITION FOR ENTIRE TUNNEL ACCESS

I. AMBIENT CONDITION TO AMBIENT TEST

1. Close and secure all tunnel accesses.

2. Close dry air inlet valve.

3. Start fan.

4. Attain test conditions by controlling fan speed, cooling coil water flow, and pressure.

5. Perform test.

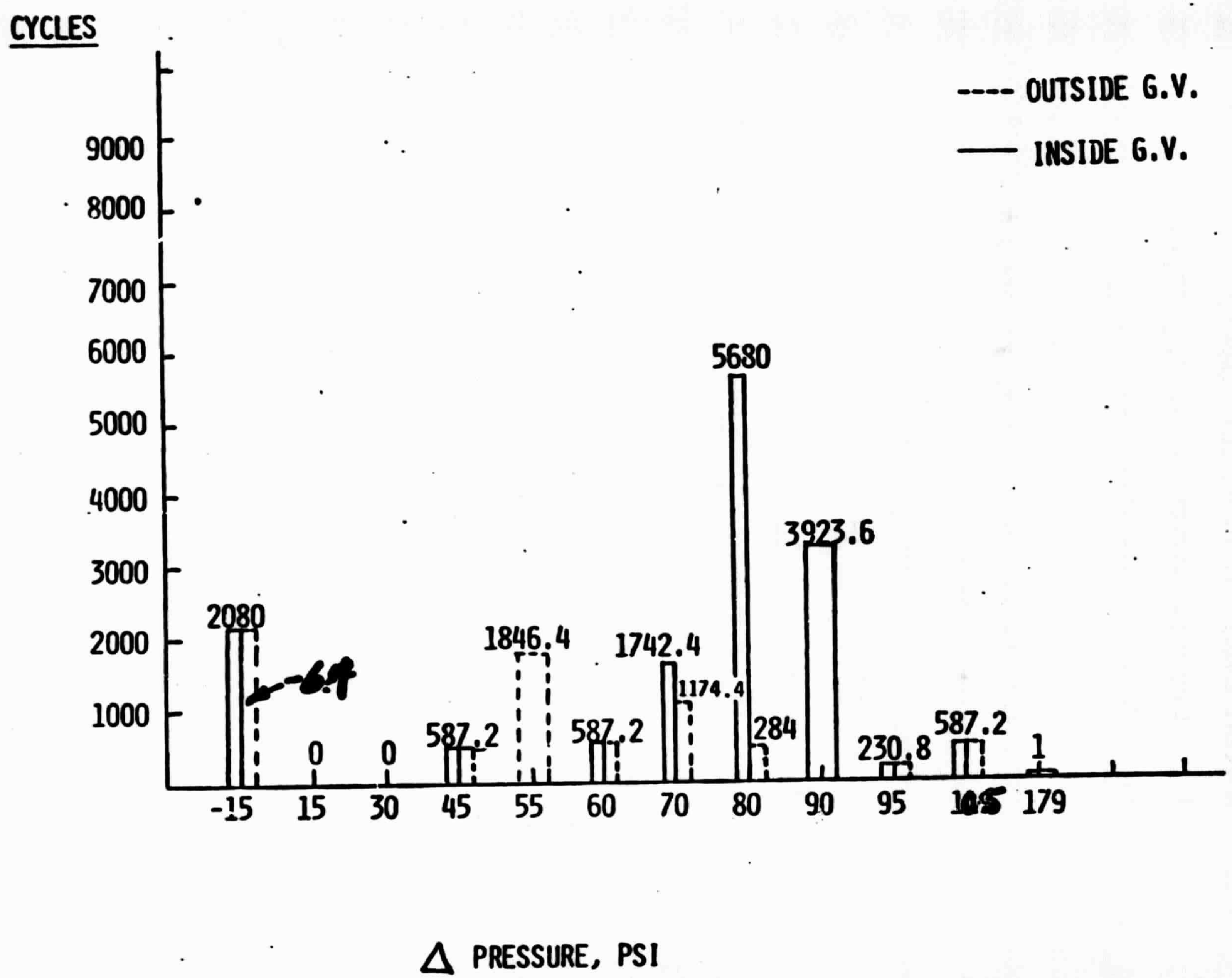
II. AMBIENT TEST TO AMBIENT CONDITION

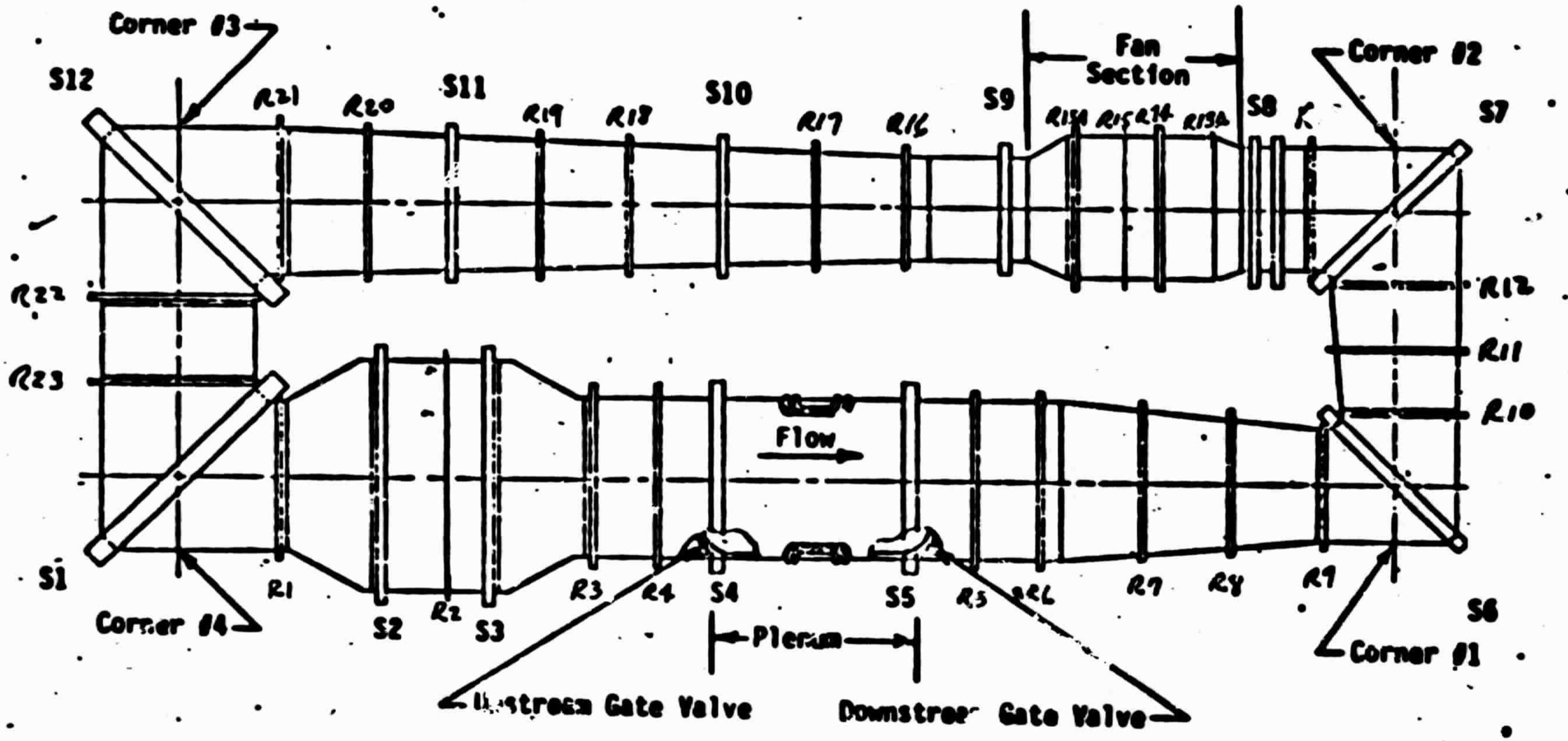
1. Shut off fan.

2. Open dry air inlet valve to maintain positive pressure of ___(TBD) psia in tunnel.

3. Before entering tunnel, assure that oxygen content is at least 20 percent by volume and temperature above 500°R.

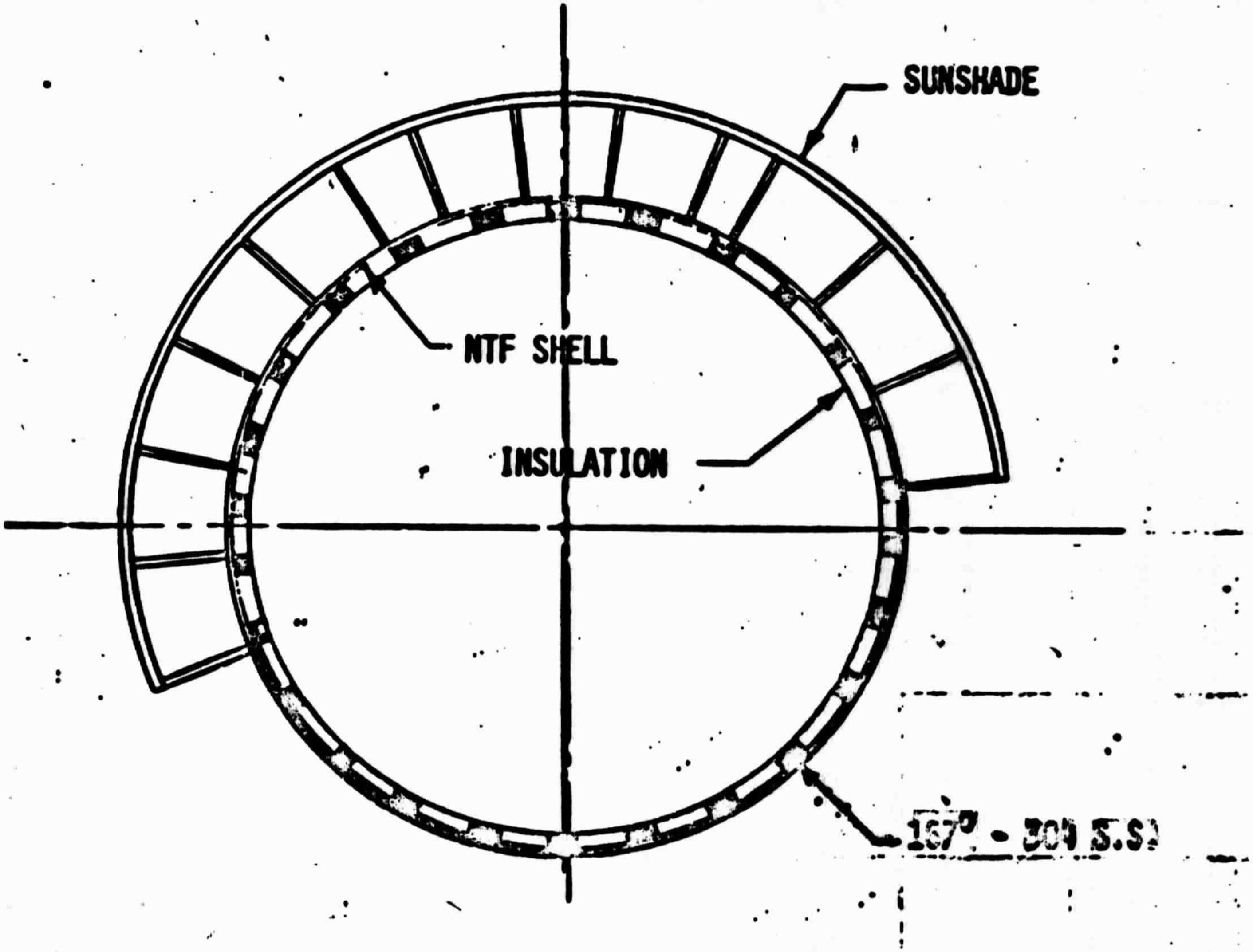
20 YEAR PRESSURE CYCL... PROJECTION OF NTF





NTF PRESSURE SHELL

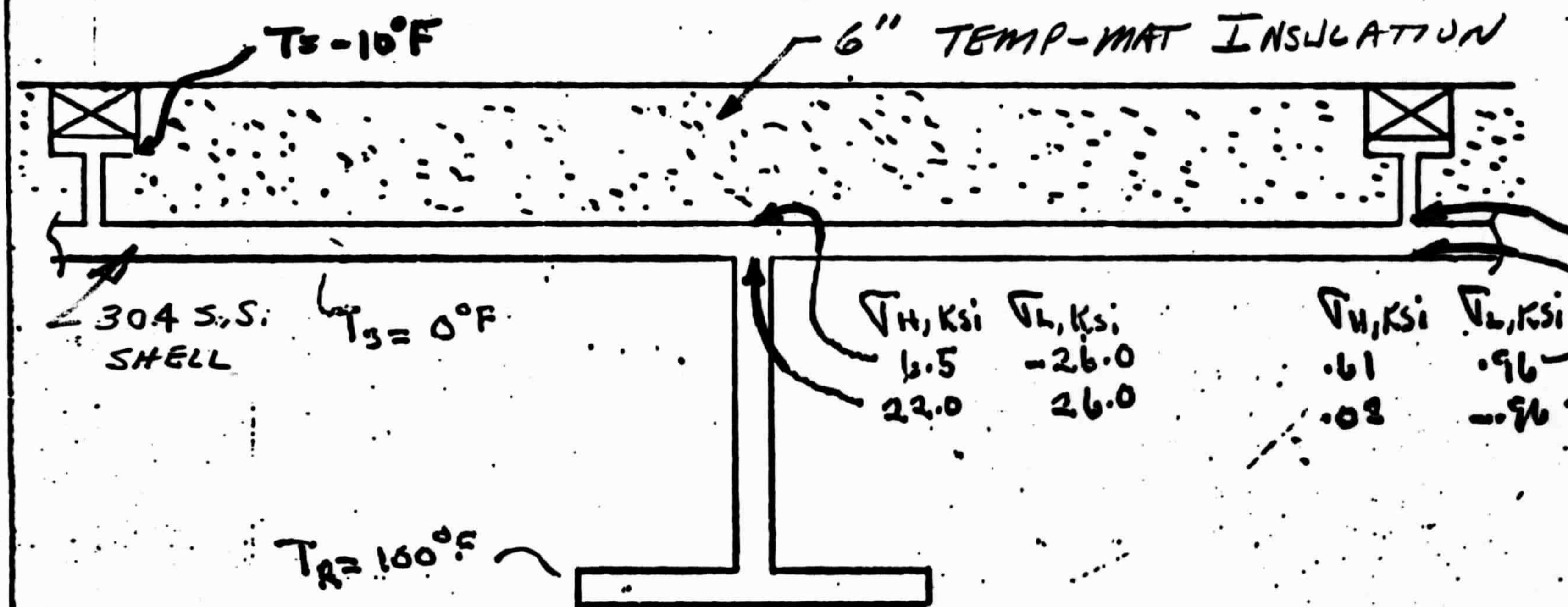
PLAN VIEW



EXTERIOR SURFACE PAINTING FOR NTF-SHELL

THERMAL PROFILE

$T_f = -280°F$



$T_a = 100°F$

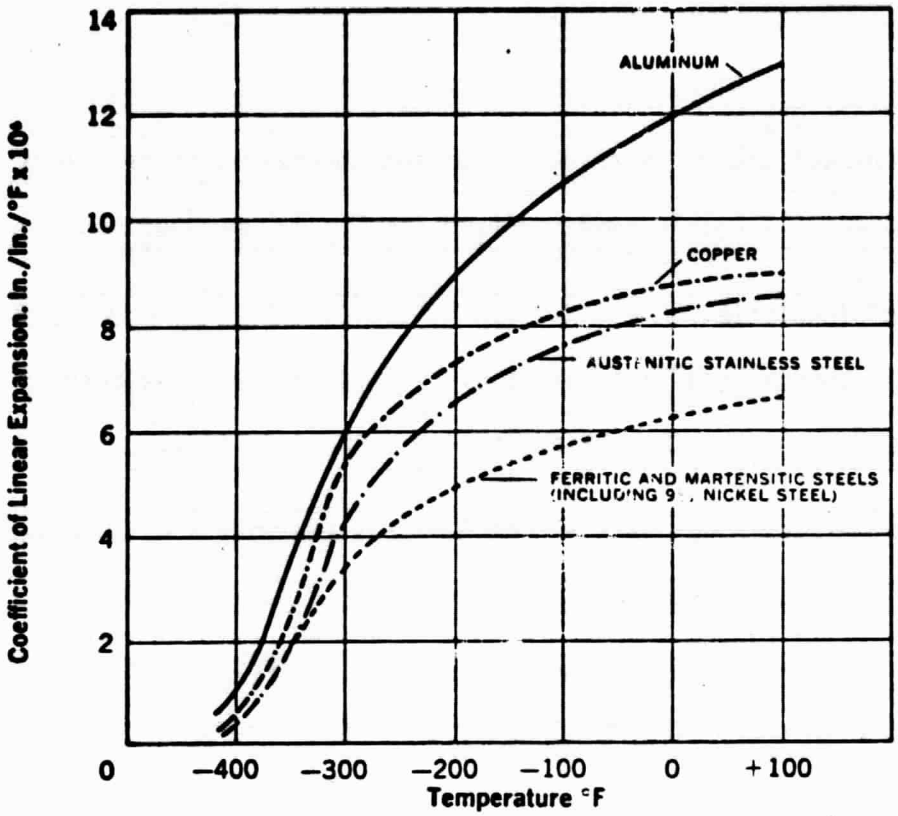
NOTE: See pp. 29A through 29C for explaniation of thermal stresses for the new Baseline Insulation - "Rohacell".

It was assumed that the 304 stainless steel thermal stresses would be the same as the 9% nickel thermal stresses. Revised thermal stresses affect only two general locations in the tunnel with a >50-year life requirement. These locations are (1) reinforcement around the 9 x 12 openings and (2) all external structural vacuum and support rings. The peak surface stress used in both 9% nickel and 304 stainless steel designs was 26 ksi for a "temp-mat" insulation.

For 9% nickel, a thermal gradient stress of 11.3 ksi and a worse case thermal profile of $\Delta T = 40^{o}F$ from top to bottom of shell would yield an additional very conservative (based on liquid pooling analysis) stress of 12.0 ksi. Calculations have indicated the ΔT might really be $20^{o}F$ and the liquid pooling analyses is too conservative; however, the difference of 23.3 ksi rather than the 26 ksi would provide a minor gain in life for 9% nickel.

The attached sheets show the average thermal expansion coeffificents would be 5.5×10^{-6} (9% nickel) and 7.3×10^{6} (304 stainless steel). The calculation of the ratio of these coefficients times the ratio of the moduli of elasticity times the 23.3 ksi 9% nickel thermal stress provides a 304 stainless steel thermal stress of 32.0 ksi. The life impact on the 304 stainless steel shell due to the 32 ksi stress rather than a 26 ksi stress is as follows: (1) 9 x 12 openings reinforcement, 48 years rather than the previously reported >50-year life; and (2) all external vacuum support rings, 46 years rather than the previously reported >50-year life.

The new baseline "Rohacell" insulation practically eliminates thermal stresses for either 9% nickel or 304 stainless steel shells. The new Baseline Insulation is a closed cell material, which results in reducing the Thermal stresses on page 29 by a factor of 7.0.



Coefficient of Linear Expansion of Several Materials

FROM "LOW TEMPERATURE AND CRYOGENIC STEEL MATERIAL MANUAL"

by U.S. STEEL

Selected Thermal Properties of Some Steels

1½% Nickel Steel	
Thermal Expansion Coefficient	
0 to +200°F	6.15×10^{-6} in./in./°F
Thermal Conductivity	
−150°F (mean)	214 Btu/in./hr./ft²/°F
+68°F (mean)	253 Btu/in./hr./ft²/°F
+200°F (mean)	270 Btu/in./hr./ft²/°F
Specific Heat	
−150 to −80°F	0.798 Btu/lb./°F
+80 to +1000°F	0.147 Btu/lb./°F
9% Nickel Steel	
Thermal Expansion Coefficient	
At room temperature	5.8×10^{-6} in./in./°F
300 to 0 F (avg.)	5.3×10^{-6} in./in./°F → 5.5×10^{-6}
−300 to −200 F (avg.)	5.6×10^{-6} in./in./°F
at −300 F	4.0×10^{-6} in./in./°F
Thermal Conductivity	
−320 F	91.3 Btu/in./hr./ft²/°F
−150 F	169.0 Btu/in./hr./ft²/°F
−68 F	189.0 Btu/in./hr./ft²/°F
+200 F	209.0 Btu/in./hr./ft²/°F
Specific Heat	
−320 to −80 F	0.0879 Btu/lb./°F (avg.)
+80 to +700 F	0.119 Btu/lb./°F (avg.)
304 Stainless Steel	
Thermal Expansion Coefficient	
+32 to +212 F	9.6×10^{-6} in./in./°F
−300 to −70 F (mean)	7.3×10^{-6} in./in./°F
+70 to +1000 F (mean)	10.0×10^{-6} in./in./°F
at −300 F	5.9×10^{-6} in./in./°F
Thermal Conductivity	
−320 F	56.4 Btu/in./hr./ft²/°F
−155 F	90.0 Btu/in./hr./ft²/°F
−70 F	113.0 Btu/in./hr./ft²/°F
+600°F	120.0 Btu/in./hr./ft²/°F
Specific Heat	
−320°F	0.037 Btu/lb./°F (avg.)
−150 F	0.088 Btu/lb./°F (avg.)
+80°F	0.120 Btu/lb./°F (avg.)

FROM "LOW TEMPERATURE AND CRYOGENIC STEEL. MATERIAL MANUAL."

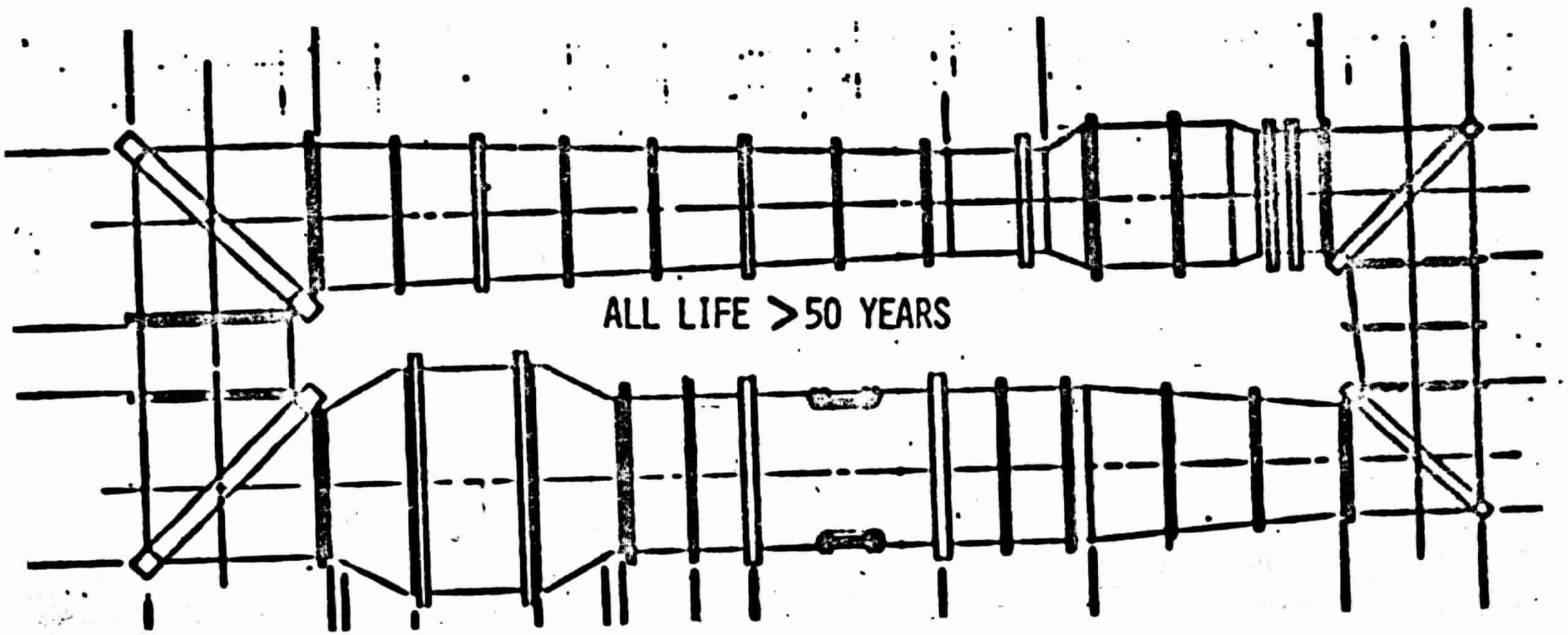
by U. S. STEEL

304 STAINLESS STEEL LIFE CYCLE for a "Rohacell" Insulation

DESIGNATION	FATIGUE LIFE (YRS)	INSPECTION SCHEDULE (YEARS)									
		5	10	15	20	25	30	35	40	45	50
S 1	50+										
R 1											
S 2											
S 3											
R 3											
S 4											
S 5											
R 6											
R 9											
S 6											
R 10											
R 12											
S 7											
S 8											
R 13A											
R 15A											
S 9											
R 21											
S 12											
9 x 12 DOOR											
DOOR REINF. FRAME											
FRAME RING											
FORGING JOINT											
GUSSETS											
BULKHEAD FLANGE[1]											
FLANGE[2]											
MID FLANGE											
OUTER FLANGE											
OUTER RINGS											
INSULATION TABS											
PENETRATIONS											
INTERIOR BRACKETS											
LONGITUDINAL WELD											
CIRCUMF. WELDS											

INTERNAL INSULATION
HTF PRESSURE SHELL

304 STAINLESS STEEL



NTF QC PROGRAM FOR CONSTRUCTION — ASME CODE EQUIVALENT SECT. 8 DIV. 2 & SECT. 3

- NEAR 100% X-RAY PRESSURE WELDS
- DYE PENETRANT WELD PASSES
- 100% ULTRASONIC EXAMINATION OF PLATES
- WELDING PER ASME SECTION 9
- NONDESTRUCTIVE EXAMINATION BY ASME SECT. 5 AND 11
- CLOSE NASA/LaRC INSPECTION CONTROL
- ALL SIGNIFICANT DEFECTS REPAIRED